Monitoring and modelling landscape dynamics

Thomas Houet, Peter Verburg, Thomas R. Loveland

Monitoring and modelling landscape dynamics

Thomas Houet • Peter H. Verburg • Thomas R. Loveland

T. Houet (corresponding author)

GEODE - UMR CNRS 5602

Université Toulouse 2, 5 allée Antonio Machado, 31058 Toulouse Cedex 9, France

e-mail : thomas.houet@univ-tlse2.fr , Phone : +33 (0)5 61 50 36 28 / Fax : +33 (0)5 61 50 42 75

Peter H. Verburg

Land Dynamics Group, Wageningen University, PO Box 47, 6700 AA Wageningen, The Netherlands

Thomas R. Loveland

U.S. Geological Survey Earth Resources Observation and Science (EROS) Center 47914 252nd Street, Sioux Falls, SD 57198-0001 USA

Version: 19/12/2013

Manuscript word count (including text, references, tables, and captions): 3033 words

Introduction

Changes in land cover and land use are among the most pervasive and important sources of recent alterations of the Earth's land surface. Land changes significantly affect key aspects of Earth System functioning, for example in contributing to local and regional climate change as well as to global climate warming, impacting biodiversity and water quality, or increasing soil degradation (Vitousek et al 1997; Stohlgren et al 1998; Houghton et al 1999). Landscape dynamics studies integrating human-environment interactions and related to environmental issues have become increasingly important. Over the years these studies moved away from a focus on detecting and identifying land use and land cover changes (Lambin et al 2001; Loveland et al 1999, 2002) and understanding driving forces of landscape changes (Bürgi 2004; Antrop 2005) to modelling present land systems for predicting land cover changes (Veldkamp et Lambin 2001; Corgne et al 2004; Hepinstall et al 2008) and exploring possible futures of landscapes (Verburg et al 2004; Kok et al 2007). Such studies were and are still largely supported by national and international global environmental change programs such as the Land Use and Cover Change program (Lambin et al 1999), the Global Land Project (GLP 2005), and the US Climate Change Research Program (Loveland et al 2003). They contribute to improving the understanding of natural-human interactions and they advance monitoring and modelling of landscape dynamics needed to meet the challenges of land change science (Turner et al 2007).

Monitoring landscape and land use/cover changes is considered as an essential first step to assist the identification of driving forces (Bürgi 2004) and provide the data needed for modelling. Projection of futures landscape changes requires and understanding and integration of past landscape trends, current land change processes and feedbacks, and the incorporation of plausible assumptions or scenarios. Obviously, monitoring and modelling of landscape dynamics strongly depends on the scale and objectives of the planned applications. This, in turn, determines the different techniques needed. Thus, landscape change models should be appropriate for simulating identified social, economic, and ecological processes, and their dynamics and interactions that shape landscapes. Land change models that are founded in land use theory and that consider land use history is also important and offer new opportunities for interdisciplinary research.

Landscape dynamics studies were and are often driven by disciplines other than landscape ecology although techniques and concepts from landscape ecology have consistently contributed to landscape change studies (Naveh 1991; Bürgi and Russell 2001; Antrop 2002). For example, the remote sensing community is regularly involved in monitoring landscape dynamics. Various disciplines, such as geography, offer diversified points of view and approaches that enable understanding the dynamics of landscape structure and function at different spatial and temporal scales.. The need for the integration of landscape history, including past/current dynamics and feedbacks has been increasingly recognized (Caspersen et al 2000; Nabuurs et al 2003; Antrop 2005; Rhemtulla and Mladenoff 2007; Claessens et al 2009; Gillson 2009). This special issue focuses on multidisciplinary research in land change science that illustrate how innovative data integration, analytical methods and techniques, and perspectives from geography, ecology, agronomy and computer sciences can help foster cross-disciplinary research with landscape ecologists (Hobbs 1997).

This special issue adds to the existing literature on the state of the art on landscape dynamics studies (Turner et al 2007; Milne et al 2009; Kok et al 2007; Lambin and Geist 2006). It also illustrates both current advances and challenges for monitoring and modelling landscape dynamics. Selected papers in this volume illustrate key dimensions of land change science, highlight possible new directions of research such as the reinforcement of multi-scale (Verburg, 2006) or human/nature (Milne et al 2009) modelling approaches, and present integrated approaches to project future landscape changes (Kok et al 2007). Most of the papers in this issue were selected from presentations at the international symposium "Spatial landscape modelling: from dynamic approaches to functional evaluations" that took place in Toulouse (France) from 3rd to 5th of June 2008 (http://w3.geode.univ-tlse2.fr/rtp-modelisation/).

Monitoring and modelling landscape dynamics: current practices, limits and new directions

Monitoring landscape dynamics is essential for understanding the complex interactions between social, environmental and geophysical processes (Munroe and Müller, 2007). Land use and land cover change studies are often based on information on landscape structure and composition at different spatial and temporal resolution that is derived from remotely sensed data (Loveland et al 2000; Goetz 2007; Coops et al, 2009). However, there are several challenges associated with developing the remote sensing inputs needed to understand landscape dynamics. The first challenge is to maintain continuous time series of low cost imagery (Turner et al 2007). The planned 2012 launch of the Landsat Data Continuity Mission, for example, extends the Landsat record an additional 5-10 years. New data acquisition systems with high spatial and temporal resolutions (i.e. Formosat, VENµS missions) are also extremely promising sources of remotely sensed data that will further enable monitoring landscape dynamics at fine spatial and temporal scales. Improvement of techniques combining multi-scale / multi-sensors / multi-source data studies show potential to rescale land cover data (Gardner et al 2008) in order to improve common landscape monitoring methods. New direction to better understand landscape dynamics include moving from land cover to land use systems such as the detection of cropping systems. The paper of Lazrak et al (this issue) in this volume lays out an innovative use of data mining techniques to detect landscape regularities over time.

This special issue also presents new directions in modelling landscape dynamics. Agent-based models have primarily been used to simulate local land use and land cover changes processes with a focus on decision making (Le 2008; Matthews et al. 2007; Parker et al. 2003; Bousquet and Le Page 2001).Valbuena et al (this issue) present an agent-based modelling approach that is also applicable at the regional scale and links individual decision making to changes in landscape structure. Innovation is not only found in new or improved models, but also in the combination of existing models. Gaucherel et al (2009) reports on research in which multiple process-based models are coupled to evaluate ecological and aesthetic impacts of landscape changes. Verburg et al (this issue) illustrate the application of multiple models at different scales to explore possible landscape trajectories in Europe. Along with with Valbuena et al (this issue), Sohl et al (this issue), and Houet et al (this issue), Verburg et al (this issue) point out the need for improved integrated land change models that connect local-to-global scales and land use pattern with land use change processes. If models are becoming more and more efficient to simulate processes at multiple scales, there is an obvious strong convergence between local scales models attempting to take into account global driving forces and regional/global models looking for finer spatial rendering at elementary landscape units (Sohl 2007; Castella et al 2007; Verburg et al 2008).

The papers in this issue also highlight land change science challenges associated with improved prediction of land use change (Lambin et Veldkamp 2001), better integration of the land system (Kok et al, 2007), and the need for advanced scenario-based studies (Verburg et al 2006). Sohl et al (this issue) and Houet et al (this issue) each propose a framework, at regional and local scales respectively, to include landscape trends and histories, to choose, parameterize, and validate models, and to explore multiple land change scenarios. Whatever the spatial scale of such approaches, data availability remains an ongoing challenge thus reinforcing the importance of landscape monitoring using multisource data (historical maps, remotely sensed data, etc). Gibon et al (this issue) illustrates the need for an integrated and participatory approach that considers socio-ecological processes in the modelling and elaboration of scenarios. Regarding exploration of alternative land change futures, Verburg et al (this issue) assess possible future landscape changes based on contrasted scenarios. This provides a good indicator of likely future land configurations. This future dimension of landscape dynamic studies provides a helpful tool to delimit the envelope of possible landscape futures and to define the plausibility of the occurrence of futures landscape changes.

Finally, all of the papers in this special issue indicate that 'standard' monitoring and modelling techniques are not always valid or the most appropriate. Land cover monitoring does not always detect subtle changes within the landscape, e.g., changes in landscape elements and change in land management practices. Models should better represent such subtle landscape changes given the importance of such changes for the functioning of the landscape (Houet et al this issue). At the same time land use (cropping) systems that show specific landscape temporal patterns and cycles that are not easily observed from traditional land cover data, but have importance for the dynamics in the landscape (Lazrak et al this issue). Moreover, landscape dynamics studies need to go further in combining modelling approaches and techniques (Gaucherel et al this issue; Gibon et al this issue; Sohl et al this issue; Valbuena et al this issue) and projecting landscape dynamics to reduce uncertainties of the futures of landscape (Verburg et al this issue; Houet et al this issue). The temporal dimension of landscapes has to be considered as important as the spatial dimension in order to monitor, model, and assess human/nature interactions. Collectively, these considerations open new directions for research in land change science.

Acknowledgements

This special issue is one of the results of the symposium “Spatial landscape modelling: from dynamic approaches to functional evaluations” that occurred in Toulouse in June 2008, supported by the French Thematic Interdisciplinary Network on «Landscape and Environment» of the department Human and Social Sciences of CNRS (National Centre for Scientific Research), the Region Midi-Pyrénées, the Toulouse Le Mirail University and the GEODE UMR 5602. We would like to warmly thank all the reviewers that have contributed to this issue by their constructive comments.

References

Antrop M (2005) Why landscapes of the past are important for the future? Landscape and Urban Planning 70:21-34

Baker WL (1989) A review of models of landscape change. Landscape ecology, 2:111-135

Bousquet F and Le Page (2004) Multi-agent simulations and ecosystem management: a review. Ecol Model 176:313–332

Bürgi M and Russell EWB (2001) Integrative methods to study landscape changes. Land Use Policy 18:9-16

Bürgi M, Hersperger AM and Schneeberger N (2004) Driving forces of landscape change - current and new directions. Landscape Ecol 19:857-868

Caspersen JP, Pacala S, Jenkins J, Hurtt G, Moorcroft P and Birdsey R (2000) Contribution of land-use history to carbon accumulation in U.S. forest. Science 290:1148-1151

Castella JC, Kam SP, Quang DD, Verburg P and Hoanh CT (2007) Combining top-down and bottom-up modelling approaches of land use/cover change to support public policies: Application to sustainable management of natural resources in northern Vietnam. Land Use Policy 24:531-545

Claessens L., Schoorl J.M., Verburg PH, Geraedts L and Veldkamp A (2009) Modelling interactions and feedback mechanisms between land use change and landscape processes. Agriculture, Ecosystems and Environment 129(1-3):157 - 170
Coops NC, Wulder MA and Iwanicka D (2009) Demonstration of a satellite-based index to monitor habitat at continental-scales. Ecological Indicators 9(5):948-958
Corgne S, Hubert-Moy L, Dézert J and Mercier G (2004) Land cover change prediction with a new theory of plausible and a paradoxical reasoning, *in* Advances and Applications of DSmT for Information Fusion, F. Smarandache and J. Dezert Editors, Am. Res. Press, Rehoboth, June 2004.
Gardner RH, Lookingbill TR, Townsend PA and Ferrari J (2008) A new approach for rescaling land cover data. Landscape Ecology 23:513-526
Gaucherel C, Griffon S, Misson L and Houet T (2009) Combining process-based models for future biomass assessment at landscape scale, Landscape Ecology (this issue) http://dx.doi.org/10.1007/s10980-009-9400-6
Gaucherel C and Houet T (2009) Preface to the selected papers on spatially explicit landscape modelling: current practices and challenges. Ecological Modelling, http://dx.doi.org/10.1016/j.ecolmodel.2009.06.025
Gibon A, Sheeren D, Monteil C, Ladet S and Balent G (2009) Modelling and simulating change in reforesting mountain landscapes using a social-ecological framework, Landsacpe Ecology (this issue)
Gillson L (2009) Landscapes in time and space. Landscape Ecology 24:149-155
GLP (2005) Science Plan and Implementation Strategy. IGBP Report No. 53/IHDP Report No. 19. IGBP Secretariat, Stockholm. 64pp. online: http://www.globallandproject.org/Documents/report_53.pdf (accessed March 2009)
Goetz S (2007) Crisis in Earth observation. Science 315:1767-1767 http://dx.doi.org/10.1126/science.1142466
Hepinstall JA, Alberti M and Marzluff JM (2008) Predicting land cover change and avian community responses in rapidly urbanizing environments. Landscape Ecol 23:1257-1276
Hobbs R (1997) Future landscapes and the future of landscape ecology. Lands Urban Plan 37:1-9
Houet T, Loveland TR, Hubert-Moy L, Gaucherel C, Napton D, Barnes CA and Sayler KL (2009) Exploring subtle land use and land cover changes: a framework for future landscape studies, Landscape Ecology (this issue) http://dx.doi.org/10.1007/s10980-009-9362-8
Houghton RA, Hackler JL and Lawrence KT (1999) The US carbon budget: Contributions from land-use change. Science 285:574-578
Kok K, Verburg P and Veldkamp T (2007) Integrated Assessment of the land system: The future of land use. Land Use Policy 24:517-520
Lambin EF, Baulies X, Bockstael N, Fischer G, Krug T, Leemans R, Moran EF, Rindfuss RR, Sato Y, Skole D, Turner BL and Vogel C (1999) Land-use and land-cover change (LUCC): Implementation strategy, IGBP, Stockholm/Bonn
Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li XB, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skanes H, Steffen W, Stone GD, Svedin U, Veldkamp T, Vogel C and Xu JC (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environ Change Hum Policy Dim 11:261-269
Lambin EF and Geists H (2006) Land-Use and Land-Cover Change. Local Processes and Global Impacts, Global Change - The IGBP Series, Springer – Berlin Heidelberg New-York, p. 222
Lazrak G, Mari JF and Benoît M (2009) Landscape regularity modelling for environmental challenges in agriculture, Landscape Ecology (this issue) http://dx.doi.org/doi:10.1007/s10980-

009-9399-8
Le QB, Park SJ, Vlek PLG, Cremers AB (2008) Land-use dynamic simulator (LUDAS): a multi-agent system model for simulating spatio-temporal dynamics of coupled human-landscape system. I. Structure and theoretical specification. Ecol Informatics 3:135–153
Loveland TR, Estes JE and Scepan J (1999) Introduction: Special Issue on Global Land Cover Mapping and Validation. Photogramm Eng Remote Sens 65(9):1011-1012
Loveland, T.R., Gutman, G., Buford, M., Chatterjee, K, Justice, C.J., Rogers, C., Stokes, B., and Thomas, J., 2003. Chapter 6: Land Use/Land Cover Change. In Strategic Plan for the Climate Change Science Program. U.S. Climate Change Science Program, Washington, D.C. 118-134.
Loveland TR, Reed BC, Brown JF, Ohlen DO, Zhu J, Yang L. and Merchant JW (2000) Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data. International Journal of Remote Sensing, 21(6-7):1303-1330
Loveland TR, Sohl TL, Stehman SV, Gallant AL, Sayler KL and Napton DE (2002) A strategy for estimating the rates of recent United States land-cover changes. Photogramm Eng Remote Sens 68:1091-1099
Matthews R, Gilbert N, Roach A, Polhill J, Gotts N (2007) Agent-based land-use models: a review of applications. Landscape Ecol 22:1447–1459
Milne E., Aspinall RJ and Veldkamp TA (2009) Integrated modelling of natural and social systems in land change science, Landscape Ecology, http://dx.doi.org/doi.10.1007/s10980-009-9392-2
Munroe DK and Müller D (2007) Issues in spatially explicit statistical land use/cover change (LUCC) models: Examples from western Honduras and the Central Highlands of Vietnam. Land Use Policy, 24:521-530
Nabuurs GJ, Schelhaas MJ, Mohren GMJ and Field CB (2003) Temporal evolution of the European forest sector carbon sink from 1950 to 1999. Global Change Biology 9:152-160
Naveh Z (1991) Some remarks on recent developments in landscape ecology as a transdisciplinary ecological and geographical science. Landscape Ecology 5:65-73
Parker DC, Manson SM, Janssen MA, Hoffmann MJ, Deadman P (2003). Multi-agent systems for the simulation of land use and land use change: a review. Ann. Assoc. Am. Geogr. 93:314–337
Rhemtulla JM and Mladenoff DJ (2007) Why history matters in landscape ecology. Landscape Ecology 22:1-3
Sohl TL, Sayler KL, Drummond MA and Loveland TR (2007) The FORE-SCE model: a practical approach for projecting land use change using scenario-based modeling. J Land Use Science 2:102-126
Sohl TL, Loveland TR, Sleeter BM, Sayler KL and Barnes CA (2009) Addressing foundational elements of regional land-use change forecasting, Landscape Ecology (this issue) http://dx.doi.org/doi.10.1007/s10980-009-9391-3
Stohlgren, Thomas J., Thomas N. Chase, Roger A. Pielke, Timothy G.F. Kittel, and Jill S. Baron. 1998. Evidence that local land use practices influence regional climate and vegetation patterns in adjacent natural areas. Global Change Biology 4: 495-504.
Turner II BL, Lambin EF and Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. PNAS 104(52):20666-20671
USGS (2008) Geographic Analysis and Monitoring program – 5 year program plan (2008-2013), online: http://gam.usgs.gov/pdf/GAM_5-Year_Plan.pdf (accessed Sept 2009)
Valbuena D, Verburg P, Bregt AK and Ligtenberg A (2009) An agent-based approach to model land-use change at a regional scale, Landscape Ecology (this issue) http://dx.doi.org/doi.10.1007/s10980-009-9380-6
Veldkamp A and Lambin EF (2001) Predicting land-use change. Agric Ecosyst Environ 85:1-

6
Verburg P, Schot P, Dijst MJ and Veldkamp A (2004) Land use change modelling: current practice and research priorities. GeoJournal 61(4):309-324
Verburg, P.H. 2006. Simulating feedback in land use and land cover change models. Landscape Ecology, 21(8): 1171-1183.
Verburg P, Rounsevell MDA and Veldkamp TA (2006) Scenario-based studies of future land use in Europe, Agric Ecosyst Environ 114(1):1-6
Verburg P, Eickhout B, van Meijl H (2008) A multi-scale, multi-model approach for analyzing the future dynamics of European land use. Ann Regional Science 42:57-77
Verburg P, van Berkel DB, van Doorn AM, van Eupen EM and van den Heiligenberg HARM (2009) Trajectories of land use change in Europe: a model-based exploration of rural futures, Landscape Ecology (this issue) http://dx.doi.org/doi.10.1007/s10980-009-9347-7
Vitousek PM, Mooney HA, Lubchenco J and Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494-499